

MARSH

Phosphorus Fertilizers

Agriculture

B. S.

1904.

UNIVERSITY OF ILLINOIS
LIBRARY

BOOK

1904

CLASS

M35

VOLUME



767 2169
62

THE COMPARATIVE VALUE OF DIFFER-
ENT FORMS OF PHOSPHORUS
FERTILIZERS

BY

GEORGE REQUA MARSH

THESIS

FOR THE DEGREE OF BACHELOR OF SCIENCE
IN THE COLLEGE OF AGRICULTURE

UNIVERSITY OF ILLINOIS

1904



Digitized by the Internet Archive
in 2013

<http://archive.org/details/comparativevalue00mars>

UNIVERSITY OF ILLINOIS

May 30, 1904

THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

George Requa Marsh

ENTITLED "The Comparative Value of Different Forms of Phosphorus
Fertilizers"

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE

OF Bachelor of Science in Agriculture

C. G. Hopkins

HEAD OF DEPARTMENT OF Agronomy

66120

I N T R O D U C T I O N

The object of this study on the comparative values of different forms of phosphorous fertilizers, is to bring together the results of work done at the different agricultural experiment stations in the United States and England, and if possible to arrive at some definite conclusions in regard to the relative merits of some of the most common phosphorous fertilizers.

Phosphorous is absolutely essential to the growth of plants and the formation of seeds. It has been well established that the salts of phosphorous acid, which are commonly known as phosphates, are the only sources from which the plant can derive phosphorous.

Phosphorous usually occurs in the soil in combination with lime, magnesia, alumina, and iron. These phosphates are all practically insoluble in water, that is they are dissolved by pure water so slowly and to so slight an extent that they are not appreciably lost from the soil in drainage water; so that, erosion of rolling lands not being considered, practically none is removed from the soil except through the agency of the crops.

As has already been stated, phosphorous exists in the soil in combination with lime, magnesiur, alumina and iron in the form of phosphates, and it is in these same combinations in which it is found in the various sources from which the phosphorous fertilizers are manufactured. In nature the phosphates are found in an insoluble form. In manufacturing fertilizers from the natural phosphates the aim is usually to convert the phosphate into the soluble form, so that it will be more rapidly available to the plants. In nature the insoluble phosphates exist in



the form known as tricalcium phosphates. In the course of manufacture this is changed chemically so that at the end of the operation four kinds or combinations of calcium and phosphorous exist, which are as follows:

- (1) Soluble phosphate of lime, or monocalcium phosphate,
- (2) Reverted phosphate of lime, or dicalcium phosphate,
- (3) Insoluble phosphate of lime, or tricalcium phosphate,
- (4) Tetra-calcium phosphate.

Soluble phosphate of lime is known under several names as; "Super-phosphate", "Superphosphate of lime", "Acid phosphate". "Water soluble phosphate", "Mono-calcium phosphate". Phosphorous is made soluble by treating bones or mineral phosphates with sulphuric acid. The chemical change which takes place is as follows; sulphuric acid and water being added to the tricalcium phosphate, the sulphuric acid combines with two parts of lime forming sulphate of lime, the water unites with the phosphorous acid and one part of lime forming the soluble monocalcium phosphate. The total conversion of the tricalcium phosphate to monocalcium form is impracticable, for such an excess of sulphuric acid would have to be used, that it would result in forming a pasty semi-liquid product.

Reverted phosphate of lime is known as; "Reverted phosphoric acid," "Reverted calcium phosphate", "Precipitated phosphate of lime", "Citrated soluble phosphate", "Neutral phosphate of lime," and "Di-calcium phosphate". It is quite insoluble in pure water but is easily dissolved in water containing carbonic acid or salts of ammonia and in weak acids. The term reverted was originally intended to imply that the phosphorous had once been soluble but for some cause had gone back to a form insol-

uble in water. This probably does take place to a limited extent, but in the course of manufacture there is not sufficient acid used to make all the phosphorous soluble, and some of the tricalcium phosphate loses only one part of lime and thus leaves some dicalcium phosphate. This form is readily available to the plant for the soil contains acid strong enough to dissolve it.

In the commercial world and in stating results of analysis the percentages of soluble and reverted phosphorous are added together and the sum called available phosphorous.

Insoluble phosphorous is known as; "Insoluble calcium phosphate", "Tri-calcium phosphate", "Bone phosphate of lime", and "Normal calcium phosphate." This form is called insoluble because it takes a strong acid to dissolve it. Insoluble phosphorous is found in nature in large deposits in Carolina, Georgia, and Florida. It is also found in small quantities in practically all soils, but in many cases it does not become available fast enough to supply the demands of the growing crops.

Tetia- calcium phosphate is a form of phosphorous of comparative recent discovery. It is found in slag phosphates, and while insoluble in water it has been found to be more available to plants than the tri-calcium form.

The table on the following page gives the approximate amount of phosphorous in the principal fertilizing materials.

Material	Percent Phosphorous	
	Total	Available
Apatite	16.7	
Bone ash	15.8	
Bone black	12.5	
Dissolved bone black	7.5	7.4
Raw bone meal	9.9	4.6
" " " from glue factory	12.7	2.9
Dissolved bone meal	7.7	3.6
Coribean guano	8.3	
Peruvian "	5.9	3.7
Florida rock phosphate	13.2	
Florida soft phosphate	10.6	
Double super phosphate	19.4	17.6
S.C. rock phosphate	12.32	0.1
" " " (dissolved)	7.0	6.2
Slag phosphate (American)	9.2	
" " (German)	13.2	
Tennessee rock phosphate	15.4	

Owing to the fact that some of the natural phosphates contain a much larger percent of phosphorous than most of the treated phosphates contain also that the cost per pound for the phosphorous is much less in the untreated than in the treated form; several experiment stations have conducted experiments in order to determine whether the cost per pound of phosphorous in the different kinds of fertilizers is in proper proportion to their usefulness to the plant.

The most important of these experiments will be discussed in the following pages.

WORK DONE AT PENNSYLVANIA

The Pennsylvania Agricultural Experiment Station began, in 1884, a series of experiments for the purpose of determining if possible the "Comparative Value of Different Forms of Phosphoric Acid." These experiments were carried on with great care, and an account of the experiment and the results, for the twelve years 1884-1895 inclusive, is given in the Pennsylvania report for 1895.

These experiments were planned and carried on by Professor H. E. Jordan up to the time of his resignation in 1889. Since that time they have been conducted by Professor Wm. Frear.

Experiments were made on the ordinary four course rotation for that section which is; wheat, grass, corn and oats. The plot for this experiment was on Experiment Station Farm and consisted of thirty six plots 1 x 8 rods, containing one twentieth acre. The surface of the land had a slight inclination to the south east, which was nearly uniform for all the plots. The soil of the plots is a so called limestone clay, formed from the decomposition of the surrounding and underlying rock, which is very largely magnesian limestone.

During 1880 and 1881 the land was in grass, (clover and timothy), and in 1882 in potatoes. No manure was applied to either crop, and no record has been kept of the yield of either hay or potatoes. No manure was applied in 1883 to any of these plots, and they were treated exactly alike as to manner and time of cultivation and quantity of seed. From the results of this crop it was evident that there was considerable irregularity in the fertility of the plots. Therefore, instead of

taking the average yield of the two plots which received no manure during the whole experiment as representing the yield of each of the plots if they had been left unfertilized, it was thought best to regard the relative natural fertility of the plots, as shown by unmanured crop of 1888 as remaining constant, and from the two unmanured plots (F. & L.) calculating the unmanured yield of each plot for each crop produced.

All the plots except F. and L. the unmanured plots, received 200 lbs. muriate of potash and 210 lbs. sulphate of ammonia per acre. Thus they were supplied with nitrogen and potash, sulphuric acid and chlorine, while the limestone soil contained a vast excess of lime, magnesia, and iron above what the crops could possibly use. Plots M. and N. received no other manuring. The remaining four pairs of plots were in addition manured with the following per acre: A. and G. 200 lbs. dissolved bone black; the phosphorous largely soluble. B. and H. 200 lbs. dissolved bone black previously treated with lime; phosphorous largely reverted. C. and I. 150 lbs. fine ground bone largely insoluble. D. and J. 150 lbs. S.C. rock phosphate; phosphorous largely insoluble.

It was unfortunately not possible to analyze the fertilizers used in these experiments but they were standard articles of trade and on the basis of the average composition of these articles the quantities above used were computed to contain about 32% phosphorous in the case of the dissolved bone black, the same for reverted and ground bone, and about 39% in the case of the S.C. rock phosphate. The plots receiving the phosphorous in the insoluble form were to this extent given an advantage over the others. It should also be added that the raw bone contains more or less nitrogen. So plots C and I received slightly more of this element than the others. With these two exceptions the

four pairs of plots differ only in the form in which the phosphorous was applied. The fertilizers were applied every alternate year, that is, (in 1884) to the wheat crop and (in 1886) to the corn crop.

In the Pennsylvania report for 1895 pages 157 to 210 give a record of the experiment for the twelve years 1884 to 1895 inclusive.

In 1884 wheat was grown on the plots and gave the following yields. S.C. rock phosphate produced the largest yield of grain (33.60 bu.) a gain of 3.30 bushels over the no phosphorous plots. Reverted phosphorous gave the largest yield of straw, and second largest yield of grain. Raw bone meal gave a slight increase over the no phosphorous plots in both grain and straw. While the plots receiving dissolved bone black gave smaller yields than the plots which received no phosphorous. This can perhaps be accounted for by the fact that a limestone soil rapidly changes a soluble phosphate into a reverted form. But even then we would expect as large a yield from these plots, as from those receiving the phosphate in a reverted form in the first place. However, such apparently unaccountable results are not infrequent in field experiments.

In 1885 grass was grown on the plots, which consisted of about two thirds red clover and one third timothy. The timothy was sown in the fall and the clover was sown in the spring each at the rate of eight pounds per acre. No fertilizer was used, so the results are due to the residue remaining in the soil from the application of 1884. The duplicate plots in some cases do not agree at all closely this year. Plots A. and B. gave larger yields than C. and D. although G. and A. both received soluble phosphorous and E. and H. received reverted phosphorous.

Reverted phosphorous gave the largest yield 1700#, a gain of 550# over the no phosphate plot. S.C. rock phosphate yielded 1350#, 50# less

per acre than the reverted plots.

In 1886 the plots received an application of fertilizer and corn was grown with the following results. Raw bone meal gave a yield of 32.86 bushels of grain, a gain of 3.35 bushels per acre over no phosphorous plots. S.C. rock phosphate stood second with a yield of 49.64 bushels, an increase due to phosphorous of 5.37. The soluble and reverted forms also gave large gains. This indicates that corn is greatly benefited by all forms of phosphorous.

In 1887 oats were grown without application of fertilizer. The plots receiving no phosphorous fertilizer produced the largest yield of grain (36.97 bu.) and insoluble phosphorous raw bone meal produced the largest yield of straw (1730%). This seems to show that oats do not require as much phosphorous as corn does, and that the natural soil contained sufficient phosphorous to produce a crop. Insoluble raw bone meal produced the second highest yield of grain (35.94 bu.) S.C. rock phosphate stood third and the dissolved bone black produced the smallest yield of any of the plots, 3.60 bushels of grain and 230% of straw less than the plot receiving no fertilizer, showing that the residual effect of this soluble phosphate is not beneficial to the following crops.

In 1888 fertilizers were applied and wheat grown. Raw bone meal was the only fertilizer that produced a gain over the no phosphorous plot, and this was only a slight increase of .22 bushels per acre. S.C. rock phosphate gave a larger yield than the soluble or reverted phosphates. It is well to note that the raw bone meal for the last three years has produced better results than any of the other fertilizers. In three years out of five dissolved bone black has given smaller yields than the no phosphate plots.

In 1888 grass was grown without application of fertilizer. Soluble fertilizer, dissolved bone black, gave the largest yield 3850%, with raw bone meal second producing 3800% per acre. Gains over no phosphorous plots were 1375% and 1320% respectively. Here as in 1885 all forms of phosphorous gave large gains. An increase of 30 to 50% over plots which received only nitrogen and potassium.

The usual application of fertilizer was made to the corn crop of 1890 and here again the raw bone meal gave the largest yield of grain, 43.03 bushels, an increase of 11.33 bushels per acre over the no phosphorous plots. S.O. rock phosphate which gave the smallest yield of any of the phosphates gave an increase due to phosphorous of 6.59 bushels per acre. These large increases show how important phosphorous is to the growth of corn.

Oats grown with no fertilizer in 1891, show the beneficial effect of the phosphates applied much more than the crop of 1887 did. Raw bone meal gave the largest yield of grain, 73.13 bushels per acre, an increase due to phosphorous of 4.29 bushels per acre. S.O. rock phosphate was second in yield of grain, producing an increase of 3.29 bushels per acre, and first in yield of straw.

With the wheat crop of 1892, the plots that received S.O. rock phosphate gave the largest yield, 26.25 bushels per acre, an increase of 2.33 bushels per acre over the no phosphorous plot. Raw bone meal stood second in yield of grain, making a gain due to phosphorous of 1.26 bushels per acre and was first in yield of straw. The dissolved bone black plots did not produce as large a yield as the plots that received no phosphorous; this was also the case with both of the previous crops of wheat.

With grass in 1893 raw bone meal gave the largest yield, 4795# per acre, an increase due to phosphorous of 945 pounds. The second largest yield was produced by S.C. rock phosphate, 4725 pounds per acre.

In 1894 the corn crop received the usual application of fertilizer, and showed, even more than in the previous years, the value of phosphorous to the growth of corn. Raw bone meal produced the largest yield of both grain and stover, giving a yield of 55 bushels per acre, an increase of 13.57 bushels due to phosphorous.

Reverted phosphorous stood second in yield, producing an increase due to phosphorous of 12.86 bushels.

With oats in 1895 S.C. rock phosphate produced the largest yield of grain. With raw bone meal the yield was almost as large. S.C. rock phosphate gave a yield of 39.16 bushels making a gain of 8.35 bushels due to phosphorous, while raw bone meal gave practically as large a yield, 39.10 bushels, making a gain of 8.29 bushels per acre due to phosphorous. The ground bone also made the largest growth of straw.

The tables on the following pages give the yield per acre of grain and straw or stover and the increase of grain or hay per acre due to phosphorous for the twelve years 1884 to 1895 inclusive.

WHEAT CROP

Yield per acre for 1884 *					
Plots	Fertilizer applied to wheat and corn	lbs. per A. of fertilizer	Grain Bu. (60%)	Straw lbs.	Gain or loss of grain due to phos.
A&B	Dissolved bone black	200	30.30	34.00	-2.50
B&C	" " " (revert)	200	35.75	36.10	+2.45
C&D	Ground bone (raw bone)	150	34.15	34.50	+0.35
D&E	S.C. Rock phosphate	150	33.60	35.00	+3.30
E&F	No phosphorous		33.30	32.50	
F&G	Nothing		26.00	22.20	

*Yields are calculated from average of the two duplicate plots in each case.

Yield of Grass per Acre - 1885.

Plot	Fertilizer applied in 1884	\$ per A. Fertilizer	Lbs. Hay	Increase due to phos.
A.&G.	Dissolved bone black	200	1500	400
B.&H.	" " " (rev'td)	200	1700	550
C.&I.	Ground bone (raw bone)	150	1500	350
D.&J.	S.O. rock phosphate	150	1650	500
E.&K.	No phosphorous		1150	
F.&L.	Nothing		1150	

Yield per acre of Corn - 1886.

Plots	Fertilizer applied	lbs. per Acre.	Ears bu. 70 lbs.	Stover	Increase of ears due to phosphorous
A&G	Dissolved bone black	200	49.29	2000	5.38
B&H	" " "	200	48.57	2000	4.66
C&I	Ground bone (raw bone)	150	52.86	2220	8.95
D&J	S.O. Rock phosphate	150	49.64	2100	5.78
E&K	No phosphorous		48.91	1700	
F&L	Nothing		34.29	1150	

Oats - yield per acre for 1887.

Plots	Fertilizer applied in 1886.	lbs. of Fertilizer	Grain bu. 32%	Straw lbs.	Increase of grain due to phosphorous.
A&G	Dissolved bone black	200	27.02	1135	-2.94
B&H	" " " (rev)	200	31.38	1260	-5.09
C&I	Ground bone (raw bone)	150	35.94	1750	-1.08
D&J	S.O. rock phosphate	150	33.44	1500	-3.58
E&K	No phosphorous		33.97	1617	
F&L	Nothing		30.63	1330	

Wheat - yield per acre, 1888.

Plot	Fertilizer applied	lbs. of Fertilizer	Grain bu. (60%)	Straw	Increase of grain due to phosphorous.
A&G	Dissolved bone black	200	31.17	2480	-3.38
B&H	" " " (rev)	200	28.58	2986	-5.92
C&I	Ground bone (raw bone)	150	34.72	3053	.22
D&J	S.O. rock phosphate	150	31.33	3140	-2.27
E&K	No phosphorous		34.50	2780	
F&L	Nothing		20.17	1540	

Grass - yield per acre, 1889

Plot	Fertilizer applied in 1888	lbs. of Fertilizer	Lbs. of Hay	Increase due to phos.
A&G	Dissolved bone black	200	3350	1375
B&H	" " " (rev)	200	3475	1000
C&I	Ground bone (raw bone)	150	3800	1325
D&J	S.O. rock phosphate	150	3500	1025
E&K	No phosphorous		2475	
F&L	Nothing		2100	

Corn - yield per acre, 1890

Plot	Fertilizer applied	lbs. of Fertilizer	Ears bu. 70%	Stover	Increase due to phos.
A&G	Dissolved bone black	200	48.00	1375	11.80
B&H	" " " (rev)	200	45.04	1750	9.24
C&I	Ground bone (raw bone)	150	48.03	1850	11.38
D&J	S.O. rock phosphate	150	43.29	1375	6.59
E&K	No phosphorous		36.70	1650	
F&L	Nothing		32.06	1000	

Oats - yield per acre, 1891

Plot	Fertilizer applied in 1890	lbs. of Fertilizer	Grain bu.-32#	Straw	Increase of grain due to phosphorous
A&G	Dissolved bone black	200	70.63	1090	1.79
B&I	" " " (rev'td)	200	70.10	975	2.26
C&I	Ground bone (raw bone)	150	73.13	1060	4.29
D&J	S.O. rock phosphate	150	72.13	1348	3.29
E&K	No phosphorous		63.84	348	
F&L	Nothing		63.80	515	

Wheat - yield per acre, 1892.

Plot	Fertilizer applied	lbs of Fertilizer	Grain bu.-30*	Straw	Increase due to phos.
A&G	Dissolved bone black	200	22.72	3213	-1.20
B&H	" " " (revtd)	200	25.38	3028	1.46
C&I	Ground bone (raw bone)	150	25.83	3493	1.96
D&J	S.O. Rock phosphate	150	23.25	3375	2.33
E&K	No phosphorous		23.92	2415	
F&L	Nothing		21.33	2068	

Grass - yield per acre, 1893.

Plot	Fertilizer applied in 1892	lbs. of Fertilizer	Hay	Increase due to phos.
A&G	Dissolved bone black	200	4100	250
B&H	" " " (rev'td)	200	4725	375
C&I	Ground bone (raw bone)	150	4795	945
D&J	S.O. rock phosphate	150	4250	100
E&K	No phosphorous		3850	
F&L	Nothing		2895	

Corn - Yield per acre, 1894

Plot	Fertilizer applied	lbs. of Fertilizer	Ears bu-70%	Stover	Increase due to phos.
A&G	Dissolved bone black	200	49.29	1950	7.36
B&H	" " " (rev)	200	54.29	2060	12.36
C&I	Ground bone (raw bone)	150	55.00	2150	13.56
D&J	S.G. rock phosphate	150	50.00	1900	8.57
E&K	No phosphorous		41.43	1650	
F&L	Nothing		32.86	930	

Oats - Yield per acre, 1895.

Plot	Fertilizer applied in 1894	lbs. of Fertilizer.	Grain bu-32%	Straw	Increase due to phos.
A&G	Dissolved bone black	200	33.59	1736	2.71
B&H	" " " (rev'td)	200	33.31	1744	7.50
C&I	Ground bone (raw bone)	150	39.10	1994	3.29
D&J	S.G. rock phosphate	150	39.16	1328	3.35
E&K	No phosphorous		33.31	1137	
F&L	Nothing		22.19	1331	

Average yield of Wheat
for three years

Plot.	Fertilizer applied every alternate year	lbs. of Fertilizer	Grain bu-30%	Straw	Increase due to phos.
A&G	Dissolved bone black	200	23.23	3014	-2.34
B&H	" " " (rev'td)	200	29.90	3203	- .67
C&I	Ground bone (raw bone)	150	31.58	3339	+1.01
D&J	S.G. rock phosphate	150	35.56	3333	+0.99
E&K	No phosphorous		30.57	2798	
F&L	Nothing		22.52	1933	

Average yield of corn per acre for
three years.

Plot	Fertilizer applied every alternate year	lbs. of Fertilizer	Bars bu-70%.	Stover	Increase due to phos.
A&G	Dissolved bone black	200	48.36	1942	8.18
B&H	" " " (rev)	200	49.60	1937	8.92
C&I	Ground bone (raw bone)	150	51.96	2072	11.23
D&J	S.O. rock phosphate	150	47.64	1908	6.96
E&K	No phosphorous		40.68	1367	
F&L	Nothing		33.07	1027	

Average yield of grass per acre for three years.

Plots	Fertilizer applied every alternate year	lbs. of Fertilizer	Hay-lbs.	Increase due to phos.
A&G	Dissolved bone black	200	3167	675.
B&H	" " " (rev)	200	3300	303
C&I	Ground bone (raw bone)	150	3365	373
D&J	S.O. rock phosphate	150	3133	641
E&K	No phosphorous		2492	
F&L	Nothing		2048	

Average yield of oats per acre for three years.

Plots	Fertilizer applied every alternate year	lbs of Fertilizer	Grain bu.-32%	Straw	Increase due to phos.
A&G	Dissolved bone black	200	43.75	1337	-1.79
B&H	" " " (rev)	200	47.10	1326	+1.53
C&I	Ground bone (raw bone)	150	49.39	1595	+3.35
D&J	S.O. rock phosphate	150	43.24	1557	+2.70
E&K	No phosphorous		45.54	1217	
F&L	Nothing		38.81	1095	

Looking over the average of each crop for the three years that it was grown we find that in every case raw bone meal produced the largest yield, S.O. rock phosphate gave nearly as good results on the wheat and oat crops but in the case of corn and grass the S.O. rock phosphate gave the smallest increase. Dissolved bone black produced a detrimental effect on the wheat crop, for in every case the plots on which dissolved bone black was used produced a smaller crop than the plots where no phosphorous was applied. It should also be noted that in the case of the crops of corn and grass the increase of yield on the soluble and reverted plots. over the S.O. rock phosphate was not sufficient to pay the difference of cost of the fertilizers. Owing to the fact that no grass crops were turned under or no farm yard manure was applied to the plots. it is probable that the soil was very deficient in humus. S.O. rock phosphate being entirely a mineral substance it needs humus to aid in its decomposition. It would be interesting to know what the effect would have been on the results of this experiment if humus had been supplied to all the plots.

Work done by the Maryland Experiment Station, which will be discussed further on, gives some valuable results on this question. In order to see which fertilizer produced the best financial results, the value of each crop was found by using the average selling price for that produce for the twelve years. That is;

Corn	was figured at	58¢,	Stover	at	\$5.00	per ton
Wheat	"	"	38¢	Straw	"	\$4.00 " "
Oats	"	"	37¢	"	"	\$4.00 " "
Hay	"	"	"	\$11.11	per ton.	

After deducting the cost of the fertilizers it was found that the

yearly average for the twelve years, gives a gain per year of \$2.83 from raw bone meal (insoluble) and \$2.45 from S.C. rock phosphate (insoluble) \$1.61 from dissolved bone black (reverted) and \$.43 from dissolved bone black (soluble).

We see in this experiment that the insoluble forms of phosphorous give by far the best results from a financial standpoint, and that the soluble forms give a very small gain.

The superiority of the raw bone meal is no doubt due largely to the fact that the limestone soil aids in the rapid decomposition of the organic matter in the bone.

OHIO WORK.

In 1888 the Ohio Experiment Station commenced a series of plot experiments with a view of obtaining light on several different points. The one in which we are interested being "Forms or carriers in which phosphorous may be most cheaply and effectually applied to the soil." Experiments along this line are being carried on at Wooster, Columbus, and Strongsville. The wooster soil is a yellow somewhat sandy clay. The Columbus soil is a much heavier clay. The soil at Strongsville is a heavy white tenacious clay.

These experiments are being carried on under the direction of Chas. W. Thorne director of the Experiment Station, and in all cases the work is carried on with great care and accuracy. In most cases the plots are tenth acre plots with a tile drain laid under every alternate alley, which divides the plots, in order to secure as near as possible perfect drainage. The four carriers of phosphorous used up to the time of the publication of bulletin 110 were: Slag phosphate, dissolved bone black, raw bone meal, acid phosphate. Plots 11, 26, 27, and 29 in the rotations at Wooster and Strongsville, and plots 11, 17, and 18 at Columbus have been used as a test of the availability of phosphorous in the different carriers.

Corn, oats, and wheat were grown in continuous culture on the farm of the Ohio State University at Columbus. The plots received the following fertilizers:

Plot 9 Muriate of potash 80% per acre, Nitrate of soda, 160%. In every case for wheat 40 pounds of dried blood were used and a correspondingly smaller amount of nitrate of soda. Plots 11, 17 and 18 received the

above in addition to the phosphorous, which was applied as follows: Plot 11, dissolved bone black up to 1887 and acid phosphate beginning with the spring of 1897. Plot 17 acid phosphate up to 1897, dissolved bone afterwards. Plot 18 slag phosphate.

The following table gives average yield of ear corn for eleven years 1888-98 inclusive; average yield of oats from 1889-98; and average yield of wheat for 1889-98 except 1896.

Average yield per acre.				
Plot	Corn	Oats	Wheat	
9	55.05	37.01	27.10	
11	54.95	33.71	30.60	
17	51.14	37.31	27.76	
18	50.88	37.10	25.87	

From these phosphorous does not seem to give any increase and no form of phosphorous can be said to be superior.

A five year rotation has been carried on at Wooster since 1894 and at Strongsville since 1895, the rotation being corn, oats, wheat and hay, two years, clover the first and timothy the second. The plots used for the comparison of phosphorous carriers 9, 11, 26, 27, 29. The total quantity of phosphorous given in the different carriers is the same, as are also the quantities of nitrogen and potash, nitrogen being supplied in nitrate of soda, alone on corn and oats, or three fourths nitrate of soda and one fourth dried blood on wheat, except on plot 26 where the

nitrogen in the bone meal takes the place of the dried blood and a part of the nitrate of soda.

Up to 1897 dissolved bone black was used as a standard carrier of phosphorous in all the tests, but in 1897 and since then acid phosphate has been used as the standard. At the same time that this change was made the carriers of phosphorous on plot 27, which had been acid phosphate was changed to dissolved bone black. Up to 1898 the acid phosphate used was made from S.C. rock, and was used on the basis of 6% available phosphorous against 7% in dissolved bone black. But beginning with 1898 Tennessee acid phosphate 7% grade has been used.

Plot 9 No phosphorous,

" 11 Dissolved bone black to 1897 acid phosphate after 1897.

" 26 Raw bone meal,

" 27 Acid phosphate up to 1897, dissolved bone black after 1897.

" 29 Slag phosphate.

The following tables give yield, and increase due to phosphorous in the five year rotation at Wooster and at Strongsville.

Average yield per acre for crops grown in five year rotation at Strongsville.								
Plot		Corn-six year ave.		Oats-five year ave.		Wheat-four year ave.		Hay-1st year
		Ears	Stover	Grain	Straw	Grain	Straw	4-yr. ave.
9	No phos	25.36	1351	34.73	1388	7.02	237	1535
11	Acid phos.	34.73	1615	43.86	1863	15.17	1431	2122
23	R.B.M.	32.56	1773	44.47	1756	15.95	1682	1437
27	D.B.P.	32.78	1735	44.43	1809	13.53	1310	2060
29	Slag phos.	34.81	1707	43.61	1703	13.95	1363	2340

Average yield of crop per acre for five year rotation at Wooster.									
Plot.		Corn		Oats		Wheat		Hay	
		7-yr. ave.		7-yr. ave.		7-yr. ave.		1-year	2-years
		Bars	Stover	Grain	Straw	Grain	Straw	6-yr. av.	5-yr. av.
9	No phos.	31.10	1613	31.90	1195	10.05	1107	2158	2680
11	Acid phos.	41.58	1841	45.63	1800	19.59	2211	2765	3246
26	R.B.M.	33.79	1927	42.71	1619	17.57	1969	2567	3356
27	D.B.M.	40.68	1919	45.63	1792	20.08	2150	2330	3268

Table showing average increase of grain due to phosphorous in five year rotation at Wooster and Strongsville.										
Plot.		Corn		Oats		Wheat		Hay		
		W.	S.	W.	S.	W.	S.	W.	W.	S.
								1-yr.	2-yr.	1-yr.
11	Acid phos.	10.43	8.90	13.73	12.13	9.54	8.15	607	553	537
26	R.B.M.	7.69	6.70	10.31	9.74	7.62	8.93	409	373	352
27	D.B.M.	9.53	6.92	13.73	9.70	10.03	6.51	172	533	475
29	Slag phos.	12.15	8.95	11.69	8.89	9.38	9.93	290	1006	735

In 1894 at Wooster and in 1895 at Strongsville an experiment with a three year rotation was commenced. The experiment at Wooster is located on the "South Farm" the soil of which does not differ materially in mechanical texture or chemical composition from that of the East Farm, on which the five year rotation is located. But the South farm has not been subjected to such exhaustive cropping as had the East farm, and it was therefore in a much better condition of fertility.

The general plan of the experiment is essentially the same as that of the five year rotation.

At Wooster six crops of potatoes, five of wheat and four of clover have been grown, and at Strongsville four crops of potatoes and three crops of wheat have been harvested; The hay crop was plowed under in order to bring the soil into better physical condition.

Fertilizers were applied to the potato and wheat crop as follows:

Plot 9 On potatoes 100 pounds of muriate of potash and 80 pounds nitrate of soda. On wheat 100 pounds muriate of potash, 120 pounds nitrate of soda and 40 pounds dried blood.

Plots 11, 27, and 29 also received this treatment: Plot 26, on which raw bone meal was used, received 100 pounds muriate of potash, 55 pounds nitrate of soda on potatoes, and 100 pounds muriate of potash and 135 pounds nitrate of soda on wheat. In addition to this treatment the phosphates were applied as follows:

Plot 11 - 130 pounds dissolved bone black previous to 1897, acid phosphate after 1896.

Plot 26 - 110 pounds raw bone meal.

" 27 - 170 pounds acid phosphate 1894-96, dissolved bone black 140 pounds in 1897 and 98, and 160 pounds in 1899.

Plot 29 - 130 pounds Slag phosphate.

The following table gives increase due to phosphorous in the three year rotation at Wooster and Strongsville.

Average Increase per Acre.								
Wooster					Strongsville			
Plot		Potatoes lbs-3 crops	Wheat-Ave. of 5 crops		Hay 4 crops lbs.	Potatoes 4 crops lbs.	Wheat-ave of 3 crops	
			Grain	Straw			Grain	Straw
11*	Acid phosphate	237	2.2	322	-270	1445	14.7	1375
23	R.B.M.	-161	3.3	576	-194	1280	15.5	1481
27*	D.B.M.	336	3.4	475	-210	1909	10.9	995
29	Slag phosphate	182	4.1	602	+513	1335	17.3	1413

*Plot 11 received dissolved bone black previous to 1897, and plot 27 received acid phosphate previous to 1897.

While in a few cases the phosphorous did not produce any increase in the crop, in most cases the increase was very decided, as it, also, was in the five year rotation; showing that the soils on which these experiments were conducted are very deficient in phosphorous. In this rotation slag phosphate is plainly in the lead, in all but three cases. And in one of the cases where raw bone meal was ahead it was only by a small margin. The superiority of the slag phosphate is especially noticeable in the hay crops at Wooster, where the other forms of phosphorous caused a loss the slag phosphate gave a large increase.

The following table gives a comparison of the different phosphates used at the different places.

Value of the average increase per acre from the different forms
of phosphorous.

CULTURE	No. of crops grown	Carriers of phosphorous							
		Acid phos		Raw bone meal		D.B.M.		Slag phos.	
		Average value of increase	Rank	Average value of increase	Rank	Average value of increase	Rank	Average value of increase	Rank
Corn 5-yr. rotation - Wooster	5	\$3.42	1	\$2.56	4	\$3.33	3	\$3.33	2
" " " Strongsville	4	2.99	3	1.85	4	3.38	1	3.38	2
Continuous - Columbus	11	3.41				2.33	3	3.11	2
Oats 5-yr. rotation - Wooster	6	3.97	2	3.47	3	4.41	1	3.41	4
" " " - Strongsville	4	3.43	4	4.08	3	4.30	1.	4.17	2
Continuous - Columbus	10	2.80	3			2.64	1	2.12	3
Wheat 5-yr. rotation - Wooster	6	8.26	2	6.92	4	8.61	1	7.38	3
" " " - Strongsville	3	7.81	4	9.77	2	8.70	3	11.13	1
3 " " - Wooster	5	6.39	4	7.54	3	7.66	2	8.11	1
" " " Strongsville	3	12.99	3	13.20	2	10.58	4	13.68	1
Continuous - Columbus	7	3.63	3			4.16	1	3.74	2
Hay All tests	17	6.29	4	1.91	3	1.92	2	2.76	1
S U M M A R Y									
Corn 5 yr. rotations	9	3.23	3	2.30	4	3.35	2	3.36	1
Oats " " "	10	3.77	2	3.71	3	4.37	1	3.71	3
Wheat both "	17	8.24	4	8.71	2	8.63	3	9.37	1
Hay " "	17	1.22	4	1.91	3	1.92	2	2.70	1

In computing the value of the different crops the following scale of prices was used:

Ear corn	-	35¢	per bushel
Oats	-	25.6¢	" "
Wheat	-	33¢	" "
Corn Stover	-	\$3.00	per ton
Oat and wheat straw		\$2.00	per ton
Mixed hay		\$6.00	" "

From this summary which includes all the cereal crops in both the three and five year rotations, also the continuous crops, and the hay grown in both rotations; we see that in three out of the four crops grown slag phosphate is in the lead; only oats giving better results where dissolved bone black was used. Summing up the increase from all the tests we find that the total average value of increase from different carriers of phosphorous in these crops to be:

From slag phosphate	\$19.14
" dissolved bone black	18.32
" raw bone meal	16.63
" acid phosphate	13.53

We, also, set another comparison with steamed bone meal from another experiment at Strongsville, in which raw and steamed bone meal were used. (on plots 15 and 16). The fertilizer being applied in the uniform quantity of 200 lbs. per acre to the crop of corn and wheat, which were grown with clover in a three year rotation. Six crops of corn and four of each wheat and hay have been harvested and are included in the results given. The net profit with the raw bone meal was \$12.28, the

the steamed bone meal, \$15.10. By means of a simple proportion we find that if the steamed bone meal were introduced into the summary given on previous page, it would rank as \$20.53, which is above any of the phosphates included in that list. This, I think, is a just comparison of the value of steamed bone meal with regard to the phosphates considered in the other Ohio experiments.

In "The Ohio Farmer" for January 2, 1904, Charles E. Thorne publishes the results of the experiments which we have been discussing, up to the present time. 18 crops of each corn and oats, 33 crops of wheat and 32 crops of hay are included in the following table which shows the average increase per acre for each fertilizer over the unfertilized yield.

Carrier	Average Increase per Acre.			
	Corn bu.	Oats bu.	Wheat bu.	Hay lbs.
Acid phosphate	12.17	13.05	11.35	612
Dissolved bone black	11.48	14.17	12.25	576
Raw bone meal	9.16	14.02	11.38	738
Slag phosphate	12.20	14.64	12.42	843

The table on the next page gives the average value per acre. Prices used are the same as given on page 25.

	Carriers of phosphorous							
	Acid phos		R.B.M.		D.B.M.		Slag phos	
	Average value of increase	Rank	Average value of increase	Rank	Average value of increase	Rank	Average value of increase	Rank
Corn	34.26	2	33.21	4	34.02	3	34.27	1
Oats	4.11	1	3.59	4	3.65	3	3.75	2
Wheat	17.44	2	18.41	1	17.44	2	17.44	1
Hay	1.34	3	2.30	2	1.73	4	2.53	1

Summing up the increase from all the tests to find that the total average value of increase from the different carriers of phosphorous to be:

Slag phosphate - - - - - \$13.75

Acid phosphate - - - - - 17.70

Dissolved bone black - - - -16.81

Raw bone meal - - - - - 15.71

We see that these results differ somewhat from the ones reported in the previous pages. However, they agree in that slag phosphate is ahead in yield for every crop except oats, where in this case, acid phosphate gave the best results. If we introduce steamed bone meal into this list by means of comparison with raw bone meal, as given in an experiment at Strongsville; we see that steamed bone meal is decidedly superior to the other phosphates. Charles E. Thorne states in the article referred to that; "At present, steamed bone meal furnishes available phosphorous in

probably the cheapest and most effective form in which it can be bought, and in view of the results above described the use of acid phosphate has been abandoned at this station except to continue experimental work, and steamed bone meal is substituted as the principal phosphate carrier in our fertilizers."

MARYLAND WORK

In In 1895 a series of experiments was begun, at Maryland with phosphates, which has given some valuable results. The general plan of the experiment was to test the availability of the different forms of phosphorous, and means of making insoluble phosphates available.

The soil on which these experiments were conducted is a moderately stiff clay, naturally quite well drained though fairly level. The general character of the plots run quite uniform.

The history of the cropping of the land is as follows; In 1888 there was a poor stand of grass which was plowed under and the field seeded to wheat which was harvested in 1889, grass was grown in 1890 and 1891, corn in 1892, fallow in 1893, and wheat in 1894, clover and timothy was seeded in the wheat which gave a good set. This was plowed under in the spring, fertilizer applied and corn planted the 25th of May.

The table on the following page gives plan and amount of fertilizers.

Plots	Kind of Fertilizer applied	Quantity per plot	Quantity per acre
1	Double superphosphate (sol)	32.00 ¹⁴	319 ¹
2	Dissolved bone black (sol)	72.5	725
3	S.O. rock phosphate (sol)	100.00	1000
4	Double superphosphate (reverted)	37.00	370
5	Nothing		
6	Iron & alumina phos. (reverted)	37.00	370
7	Bone black (insoluble)	51.4	514
8	Raw bone meal (insoluble)	66.75	667
9	Slag phosphate (insoluble)	92.00	920
10	Nothing		
11	Ground S.O. rock (insoluble)	53.00	530
12	Florida soft phos. (insoluble)	56.00	560

These plots had crimson clover seeded in corn in the fall and was turned under in the spring. Plots 13, 14, 15, 16, and 17 had the same treatment as 8, 9, 10, 11, and 12 respectively, except the corn ground was left bare during the winter and no green crop turned under. Plots 18, 19, 20, 21, 22, received the same treatment respectively as 3, 9, 10, 11 and 12 except rye was seeded on corn ground instead of clover.

The quantities of fertilizers applied gives each one tenth acre plot the same quantity of phosphorous, 66 pounds per acre.

The land which was in clover and timothy sod was plowed in the spring and the fertilizer sown broadcast by hand, in quantities shown by preceding table. Corn was planted May 25. Crimson clover was sown July 30th at the rate of seven quarts per acre on plots 1-12. Corn was

cut Sept. 19. Plots 8-22 were seeded to rye at the rate of two bushels per acre, on October 18, corn was husked and housed November 4-7.

Plots were plowed May 14, 1896 and allowed to stand until May 26, in order to let the vegetable matter partly decompose, then fertilizer was applied according to the schedule, also all plots received an application of muriate of potash at the rate of 100 pounds per acre, and corn was planted. Corn was cultivated and harvested, and clover and rye seeded practically after the same manner as was done in the previous year. In 1897 the same treatment was applied and the same crops were grown as in 1896.

In 1898 the land was so dry at time of planting that only a poor stand came up. So it was thought best to harrow up the crop which was done July 7. The plots were harrowed occasionally during the summer to keep the weeds down and were seeded to wheat September 26. Timothy was seeded at the same time as the wheat, and clover was sown the following spring.

In 1900 the grass was allowed to grow and was cut July 7 for hay.

Yields of crops are given in the following tables.

Plots 1-12 had crimson clover turned under, plots 13-22 had rye turned under; the others had nothing turned under.

Phosphorous on first three plots was soluble, on plots 4 and 6 the phosphorous was reverted. On the rest of the plots it was insoluble.

-31-
Yield per acre of corn.

	1895		1896		1897		Average	
	Grain bu.	Fodder lbs.	Grain bu.	Fodder lbs.	Grain bu.	Fodder lbs.	Grain bu.	Fodder lbs.
1. Double super phos.	46.0	2830	40.8	2100	57.9	3020	48.1	2660
2. Dissolved bone blk	38.7	2700	37.4	2200	51.1	2930	41.8	2610
3. S.C. rock (dissolvd)	39.0	2400	35.8	2340	43.6	2310	39.5	2517
4. Double super phos.	35.8	2420	37.0	2660	47.7	2920	40.2	2467
5. Nothing	42.6	2580	42.0	2200	57.3	3190	47.3	2657
6. Iron & Al. phos.	45.4	2940	43.2	2400	64.9	3330	51.2	2890
7. Bone black	36.9	2340	41.6	2130	53.1	3070	45.5	2527
8. Raw bone meal	37.8	2100	43.0	2340	61.9	3320	47.6	2537
9. Slag phosphate	33.4	2100	42.1	2320	53.4	2670	43.3	2333
10 Nothing	39.4	1980	33.6	2360	49.4	2460	42.5	2167
11 S.C. rock phos	42.4	2230	44.3	2360	60.7	3030	49.3	2530
12 Florida Soft Rock	44.0	2130	43.3	2530	63.1	3190	51.1	2650
13 Same as 8	49.4	2760	49.1	2680	53.4	2160	52.3	2367
14 " " 9	43.4	2120	44.4	2500	46.6	3130	44.8	2533
15 Nothing	41.4	2460	44.1	2360	44.1	2980	42.8	2600
16 Same as 11	47.7	2620	45.0	2420	40.4	2880	44.4	2640
17 " " 12	43.2	2700	42.4	2140	34.4	3020	41.7	2620
18 " " 8	47.1	2520	40.4	2130	42.7	2660	43.4	2453
19 " " 9	49.3	2300	45.3	2320	44.6	2930	46.4	2700
20 Nothing	50.0	2900	43.0	1900	37.0	2420	43.3	2427
21 Same as 11	45.5	2460	41.7	1900	30.1	2320	39.1	2393
22 " " 12	47.8	2760	34.3	1200	36.4	2660	39.7	2207

Fertilizer	Wheat 1899		Hay 1900
	Grain bu	Straw lbs.	Pounds
1. Double superphosphate	36.0	4140	3900
2. Dissolved bone black	37.1	4375	4200
3. S.C. rock phos. (dissolved)	37.0	2930	4950
4. Double superphosphate	31.3	3550	4250
5. Nothing	22.0	2580	4150
6. Iron & alumina phosphate	34.6	3170	4800
7. Bone black	25.6	3415	4000
8. Raw bone meal	34.5	4100	4500
9. Slag phosphate	34.8	4160	2450
10. Nothing	20.7	2300	4000
11. S.C. rock phosphate (untreated)	29.8	3710	4400
12. Florida soft rock	30.8	3800	4750
13. Same as 3	35.5	3720	2300
14. " " 9	37.6	4395	4900
15. Nothing	22.0	2180	3200
16. Same as 11	22.3	3530	3700
17. " " 12	29.1	2300	3950
18. " " 3	36.0	3390	4300
19. " " 9	36.1	4030	3300
20. Nothing	22.6	3345	4000
21. Same as 11	31.9	3235	4550
22. " " 12	30.1	2800	3350

Table showing gain or loss per acre due to Phosphorous.

	Corn: Ave. of 3 years.		Wheat one year		Hay
	Grain bu.	Stover lbs	Grain bu	Straw lbs	
1. Double supersulphate	3.2	148	14.7	1700	-175
2. Dissolved bone black	-3.1	198	15.8	1935	125
3. " S.C. rock phos.	-5.4	105	15.7	490	875
4. Double supersulphate (reverted)	-4.7	55	10.8	1110	175
5. - - - - -					
6. Iron and aluminum phosphate.	6.3	488	13.3	730	725
7. Bone black	0.6	115	4.3	975	- 75
8. Raw bone meal	2.7	175	13.2	1660	425
9. Slag phosphate	1.4	- 49	13.5	1720	-1625
10. - - - - -					
11. S.C. rock phosphate (untreated)	4.4	148	3.5	1270	325
12. Florida soft rock	6.2	238	9.5	1360	675
13. Same as 3	10.1	267	13.5	1540	-400
14. " " 9	2.6	- 17	15.6	1215	1700
15. - - - - -					
16. same as 11	2.2	40	0.8	1350	500
17. " " 12	0.5	20	7.1	620	750
18. " " 3	0.1	23	13.4	545	300
19. " " 9	3.1	273	13.5	685	-700
20. - - - - -					
21. Same as 11	-4.2	- 34	9.3	-60	500
22. " " 12	-2.6	-220	7.5	-545	650

Summary showing yields with different forms of phosphorous
per acre.

	Corn 3- crops		Wheat 1 year		Hay
	Grain	Stover	Grain	Straw	
Ave of 4 nothing plots (5,10,15,20)	43.8	2462	21.3	2301	3862
Ave of 3 soluble plots(1,2,23)	43.3	2484	36.7	3815	4350
" " 2 reverted " (4&6)	45.7	2678	32.3	3360	4525
" " 5 insoluble " (7,8,9,11,12)					
Crimson clover turned under	43.0	2537	31.1	3837	4020
Ave. of 4 insoluble plots, (8,9,11,12) Crimson clover turned under	49.0	2540	32.4	3942	4025
Ave. of 4 insoluble plots (13,14,16,17) nothing turned under	45.8	2678	33.7	3611	3838
Ave. of 4 insoluble plots, (18,19,21,22) Rye turned under	42.1	2438	33.5	3511	3900
Ave of 12 insoluble plots, (3,9,11,12,13,14,16,17,18,19, 21,22)	45.5	2552	33.2	3683	3921
Ave of 3 bone meal plots, (8,13,18)	47.8	2636	35.3	3908	3837
" " " slag phos. plots (9,14,19)	45.8	2549	36.0	4195	4217
" " " S.O. rock phos plots (11,16,21)	44.3	2531	31.5	3508	4217
" " " Florida soft phos plots (12,17,22)	44.2	2492	30.0	3147	4050

This experiment shows, as did the ones carried on at Pennsylvania and Ohio, that the soil was greatly in need of phosphorous, for with a few exceptions, phosphorous in any form produced a noticeable increase in yield. The yields of corn on the soluble plots and also on the plots where rye was turned under, were below that of the plots which received no phosphorous. This is probably partly due to the fact that the phosphorous was in a very soluble form when the plants were young, which caused so rapid a growth that they were unable to stand the dry weather later in the season. The rye which was turned under probably left the soil in such a condition that it dried out badly during the summer.

With the three years crops of corn we see that raw bone produced the largest yield of both corn and stover, and that slag phosphate stood second. This agrees very well with the Ohio and Pennsylvania work, for we remember that raw bone produced much the largest yield in the twelve year experiment at Pennsylvania, and that slag phosphate stood first in the phosphorous experiments at Ohio. (Steamed bone meal which proved superior to slag phosphate in another experiment at Ohio, and which is being used at the Ohio station farm as the carrier of phosphorous, except for experimental purposes, was not included in phosphorous experiments.) While the account of the experiments in Maryland does not give a full description of the soil, it probably contains an excess of calcium carbonate which would aid in the decomposition of the organic matter in the raw bone. In Ohio the soil being acid probably accounts for the basic slag giving better results than the raw bone.

The wheat crop in every case showed a marked increase due to phosphorous. The yield of grain was the largest on the soluble phosphorous plots. Bone black which gave the least increase caused a gain of 4.8

bushels per acre. This shows more decidedly than the corn crops did the value of phosphorous in increasing the productiveness of the soil.

The hay crop, which was clover and timothy mixed, timothy, predominating, in most cases gave an increase due to phosphorous. The largest yields were on the plots where iron and alumina phosphates were applied. The plots receiving the soluble, also the slag phosphate and untreated S.G. rock phosphate gave nearly as large yields as the reverted form.

An examination of the previous tables show that the five insoluble phosphorous plots (7,8,9,11, 12) produced an average increase of considerable more than the soluble, or reverted plots. This considered in the light of the fact that the soluble and reverted forms are much more expensive than the untreated forms, argues strongly in favor of the insoluble forms.

A very interesting and important fact is shown by a comparison of plots 3 and 9, which received raw bone and slag phosphate respectively, with plots 11 and 12 which received S.G. rock and Florida soft phosphate respectively. All these plots had crimson clover turned under in the spring. With the corn and hay the natural phosphates compare favorably with raw bone and slag phosphate. This is certainly an important fact when we remember that these natural phosphates cost about one third as much as raw bone. On the plots which received the same treatment except that no crops were turned under, the natural phosphates were inferior to the raw bone and slag phosphates. In the experiment at Pennsylvania where no crops were turned under the S.G. rock did not

give as good results as the raw bone.

The experiments at these stations bring out decisively the facts that the soils are deficient in phosphorous, and that the insoluble forms are superior to the soluble or acid forms. Also that when there is plenty of humus in the soil the untreated mineral phosphates are at least equal to raw bone or slag phosphate. And that when lime is present raw bone is superior to slag phosphate, but on an acid soil the slag phosphate is the best of the two forms.

(The work at Ohio and Maryland on phosphates is still in progress)

CONNECTICUT WORK

In Connecticut a number of co-operative experiments were conducted by farmers under the direction of the Station. Most of these experiments lasted but one year, and so are of very little value. Bartholmew conducted an experiment which lasted three years, and Yomens one that lasted two years.

Bartholmew's experiment was carried on on land that was high and gently sloping toward the southwest. The soil was a dark moist loam with a clay sub-soil. The field had been sown in rye the fall before the experiment was started, which was badly winter-killed. After plowing in the spring the following treatment was applied: 200 lbs. muriate of potash and 100 lbs. sulphate of ammonia per acre were sown broadcast. and the following phosphates applied:

Plot A Dissolved bone black -----32 lbs.

" B Gayman phosphate-----56 "

" C Slag phosphate-----37-1/2 lbs.

Plot # S.O. rock phosphate-----70 lbs.

Phosphates were applied in such quantities that the cost per plot for fertilizer would be the same. Plots C&F received no phosphorous. Corn was planted May 24, 1887, and one week later dried blood was applied to the plots at the rate of 100 lbs. per acre.

In 1888 this experiment was repeated on the same plots without application of phosphorous. In 1889 muriate of potash was applied at the rate of 320 pounds per acre, and on Jan. 20 a small quantity of bone black was sprinkled about the roots of the plants on three cross sections of one rod wide on all the plots. This increased the yield but probably did not materially effect the relative yield of the plots. The yield in bushels or pounds is not given in all cases, so the following table gives comparative yields. The average of the two nothing plots being given as 100%.

Fertilizer applied	Sound Ears.			
	1887	1888	1889	3-year Ave.
Average two nothing plots	100%	100%	100%*	100%
Dissolved bone black	144	111	100	118
Ground Gayman phos.	141	127	145	141
Slag phosphate	140	140	156	145
S.O. rock phosphate	113	127	129	125

*Total sound and soft ears.

From the table we see that all forms of phosphorous produced a marked increase the first and second year after application, and all but the dissolved bone black made as much if not more increase the third year after application than they did the year that they were applied. This experiment agrees with the ones at Ohio and Maryland in that on the whole

the slag phosphate was superior to the dissolved bone black or the S.O. rock phosphate. It also shows that for the same amount of money expended on fertilizer, the insoluble forms give the best results.

The experiment carried on by Mr. Yomans and reported in the Connecticut report for 1889, page 122 is in general the same as the one conducted by Bartholmew. The soil in this case was a yellow gravelly loam with a clayey subsoil. It had been cropped with buckwheat the year before with a dressing of acid phosphate at the rate of 150 pounds per acre. The fertilizers which were applied the year the experiment was started were 320 pounds muriate of potash and 200 pounds sulphate of ammonia per acre. The phosphates used were:

Dissolved bone black	- - - - -	13 pounds
Ground Cayman phosphate-	- - - - -	23 "
Slag phosphate	- - - - -	27-1/2 pounds
Bolivian guano	- - - - -	27-1/2 "
S.O. rock phosphate-	- - - - -	34-1/2

Plots were 1/16 acre. Corn was grown. This experiment was repeated in 1889 with the exception that no phosphates were applied. The following table gives a comparison of the different plots in percent, calling the average of the no phosphorous plots 100%.

Fertilizer	Sound Ears		
	1888	1889	Average
Average no phosphate plots	100%	100%	100%
Dissolved bone black	537	238	418
Ground Cayman phosphate	312	359	336
Slag phosphate	211	452	332
S.O. rock phosphate	191	333	290
Bolivian guano	194	392	443

This soil is evidently extremely poor in phosphorous, for the one application of phosphorous produced an average of over three times the yield of the no phosphorous plots. Since this experiment lasted only two years we cannot draw conclusions from the results, especially so on account of the unfavorable season of 1889. However, in a general way this experiment agrees with the first two years of the experiment conducted by Mr. Bartholmew. in that the dissolved bone black made a much greater increase the first year than it did the second, while the other forms of phosphorous which are largely insoluble made larger gains the second year than they did the first.

Several other farmers conducted experiments for one year only. While such experiments are of little value as comparative tests, yet it is well to note that with very few exceptions phosphorous in any form produced a marked increase in yield

In Rhode Island Agricultural Experiment Station Report for 1884, pp 122-123 there is a report of an experiment conducted by Charles O. Flagg, J.D. Tower and Geo. W. Tucker.

The plan of the experiment was to apply each of the phosphorous fertilizers used in the experiment to two plots one of which was to receive lime at the rate of 1000 pounds per acre. All the plots received 450 pounds nitrate of soda and 240 pounds muriate of potash per acre. An equal money value of phosphates were applied to each plot. Bone black at the rate of 300 pounds per acre was used as standard. The soil selected for this experiment was of a uniform type and had received no fertilizer for a number of years. The corn crop grown the year previous to the beginning of the experiment showed a marked degree of exhaustion.

The following tables give treatment that the plots received, yield of crop and also loss or gain of fertilized plots over unfertilized plots.

Yield of Corn per acre for 1894					
Plot	Fertilizer	lbs. per A. of fertilizer.	Wt. of Stover.	Bu. of Corn	Gain or loss of grain due to phos.
51 L*	Dissolved bone black	300	3710	64.4	26.9
52	" " "		1332	52.8	25.8
53 L	Dissolved bone	504	2720	51.1	12.6
54	" "		1312	33.4	11.4
55 L	Dissolved rock phosphate	927	3147	56.5	19.0
56	" " "		2545	46.5	19.5
57 L	Raw bone meal	423	1925	50.9	13.4
58	" " "		1865	32.2	5.2
59 L	Slag phosphate	766	2420	44.1	3.6
60	" "		1973	33.9	3.9
61 L	S.O. rock phosphate	927	2210	24.1	-13.4
62	" " "		1442	27.3	0.8
63 L	Raw aluminum phosphate	523	2012	20.5	-17.0
64	" " "		1537	20.9	- 3.1
65 L	Burned " "	330	1927	33.9	- 3.6
66	" " "		1232	18.8	- 8.2
67 L	No phosphate		1937	37.5	
68	" "		1507	27.0	

* The plots marked "L" received lime at the rate of 1000 lbs. per acre.

Plot	Fertilizer	lbs. per A. of Fertilizer. per A.	Estima- ted % lodged Aug. 7.	Bu. Oats per A.	Lbs. of straw per A.	Gain or loss of grain
51 L	Dissolved bone black	600	90%	36.9	5360	22.4
52	" " "	600	50	29.9	3842	19.1
53 L	Dissolved bone	550	100	29.3	9195	15.3
54	" "	500	100	31.4	4795	20.6
55 L	Dissolved rock phosphate	1200	100	32.2	8190	17.7
56	" " "	1200	100	35.4	7967	24.6
57 L	Raw bone meal	439	100	27.0	5835	12.5
58	" " "	439	100	26.3	6462	15.5
59 L	Slag phosphate	360	100	29.5	8462	15.0
60	" "	360	100	28.4	5292	17.6
61 L	S.G. rock phos. (floats)	941	100	21.9	4800	7.4
62	" " " "	941	100	23.7	4442	12.9
63 L	Raw aluminum phosphate	529	50	19.0	4092	4.5
64	" " "	529	0	15.5	3702	4.7
65 L	Burned " "	330*	50	12.7	2795	-1.8
66	" " "	330*	0	16.4	3557	5.6
67 L	No phosphate		50	14.5	4365	
68	" "		0	10.8	2855	
69 L	Double superphos	311	30	25.6	4980	11.1
70	" "	311	5	24.8	3305	14.0

* By mistake plots 65 and 66 received 193 lbs. per acre more ignited phosphate than they should have.

Hay crops for 1896 - 1899 inclusive.		Ave. per acre.	
Plot	Fertilizer	Ave. yield for three years	Ave. gain due to phos.
51 L	Dissolved bone black	6613	1367
52	" " "	3274	3424
53 L	Dissolved bone	6427	1181
54	" "	2355	2006
55 L	Dissolved rock phosphate	3735	1439
56	" " "	2934	2135
57 L	Raw bone meal	7337	2092
58	" " "	3952	3103
59 L	Slag phosphate	6800	1554
60	" "	4393	3548
61 L	S.C. rock phos. (floats)	6842	1596
62	" " " "	3520	2371
63 L	Raw aluminum phos.	4793	- 450
64	" " "	1381	832
65 L	Burned " "	3494	1243
66	" " "	1343	794
67 L	No phosphate	5243	
67	" "	349	
69 L	Double super phos.	5979	763
70	" " "	1534	735

In 1896 oats were grown on the plots and fertilizers applied as follows: nitrate of soda, 401 pounds and muriate of potash 240 pounds per acre, and phosphates applied at a rate costing \$6.60 per acre based on an application of 600 pounds of dissolved bone black per acre.

Heavy storms about the time the oats were heading out lodged them badly on the plots where the growth had been most vigorous, for this reason the yields of this year are of little account as indicating the value of the different fertilizers, it being a well known fact that when oats lodge they fail to fill with grain.

After the oat crop was harvested the ground was plowed (Aug. 17) and worked with a smoothing harrow preparatory to seeding to grass. It was decided to apply the fertilizers in the following way: to the plots that were to receive the insoluble phosphates the full ration for the three years was to be applied before seeding and thoroughly worked into the soil, so it would have every opportunity to become available. The soluble forms and the nitrogen and potassium were to be applied each spring in form of top dressings in one third the amount for the three years. However, in 1898 the direction of the experiment was given up by Mr. Flagg, to the Station chemist who decided in view of the fact that the relative cost of the phosphates had changed greatly, that it would be best to apply equal amounts of phosphoric acid instead of equal money value. By 1899 each plot had received an equal amount of phosphorus for the years 1895-99 inclusive. As has already been stated on account of the oats lodging in 1895 the yields for the first two years are of little value for comparison of the phosphates except to note that as in previous experiments in nearly every

case the phosphates caused a considerable increase.

From the four years hay crops which were grown after the plots had received the phosphates for two years previous, we get some results which are worth consideration.

In the first place we note that with one exception, (that of the raw aluminum phosphate on the lime plot), the phosphates gave a substantial gain. In the lime series raw bone stands at the head, making the gain per acre for the four years of 3403 pounds, followed by S.C. rock phosphate and slag phosphate, which run close together making gains of 4787 and 4662 pounds respectively. The soluble forms made a large increase in yield, but are not up to the three insoluble forms above mentioned. On the unlined series we find that while the soluble forms produced gains in yield are noticeably inferior to the insoluble slag phosphate, raw bone, and S.C. rock phosphate. The dissolved bone black produced the largest increase of the soluble forms, 7273 pounds per acre, for the four years. The slag phosphate, raw bone, and S.C. rock phosphate produced gains due to phosphorous of 10645, 9307 and 8012 pounds respectively. It is noticeable that the gains due to phosphorous on the unlined series are much greater than those on the lined series. We must be careful and not be misled by this and think that lime is not beneficial where phosphates are applied. The total yield on the lined series is approximately double that on the unlined series. The reason that the gains over the no phosphorous plot are greater on the unlined series than on the lined series is because the yield on the no phosphorous plot of the unlined series is very small, 2547 pounds, while the no phosphorous plot of the lined series produced 5787 pounds.

The reason for this difference between the lined and unlined no phosphorous plots is no doubt that the lime caused the natural phosphates in the soil to become more available than they were on the unlined plot.

Field experiment at Massachusetts with different commercial phosphates to study the economy of using the cheaper natural phosphates or the more costly soluble phosphates.

Conducted by S.A. Doessmann.

-oOo-

Field "F" was chosen for this experiment. Previous to 1887 it was used as a meadow which was well worn-out producing but a scanty crop of English hay. In the fall of 1887 it was plowed and allowed to remain in this state over winter. During the years 1887-88-89 no fertilizers were applied and corn and Hungarian grass leguminous crops, (cow peas, vetch and serredilla), were grown in the order named. In 1890 the field was divided into four plots. The plots all received the same amount of nitrogen and potassium per acre and an equal money value of phosphorous. The following table gives the annual treatment applied to each plot, except plot 3 which received reverted ground apatite in 1890 and no phosphorous in 1891.

Plot	Size sq. ft.	Annual application of fertilizer, 1890-93.	Pounds
1	6494	Slag phosphate Nitrate soda, 43% Potash mag. sulphate - 58	127
2	6565	Ground Mona guano N of S. 43-1/2 P Mg.S. 59	128
3	6636	Ground Florida phosphate N of S., 44, P Mg S. 59	129
4	6607	S.C. rock phosphate N of S. 44-1/2 P Mg.S. - 30	131
5	6778	Dissolved bone black N of S. 45, P Mg.S. - 31.	73

In the above table nitrate of soda was applied at the rate of 250 pounds per acre and potash magnesium sulphate at the rate of 390 pounds, and dissolved bone black at the rate of 500 pounds per acre.

	1890	1890	1891	1891	1892	1892	1893	1893	1894	1894
	Potatoes		Wheat		Serredetta		Corn		Barley	
	large	small	Grain	Straw	% per-	tons	Grain	stover-	Grain	Straw
	per A.									
.phos.slag	8153	2533	7.5	2100	4070	13.29	45.0	7935	23.3	1438
Mona guano	8075	3320	3.1	1773	3410	11.29	54.2	53.78	20.5	1657
rida phos.	7019	2821	4.2	1061	2750	9.05	40.5	3002	10.7	1399
. rock phos.	8956	2929	3.4	1953	3110	10.10	53.8	5776	19.4	1404
.M.	10176	3392	6.3	2214	2920	9.36	49.7	4992	15.7	1453

Wheat 1895 Grain-Straw		Soy Beans 1896 Beans Straw bu. lbs.		Sweedes Roots	1897 Tops.	
20.1	3350	28.3	2843	12529	3216	
18.4	3069	25.6	3534	24123	5280	
15.7	1584	28.8	3003	5412	2640	
20.5	3705	27.3	3250	12773	3640	
19.7	2816	26.3	3168	10362	2368	

We see from this table that the soluble phosphate, dissolved bone black is in the lead for the first two years, while the insoluble forms are in the lead for the third, fourth, fifth and sixth; slag phosphate first,, S.C.Rock has second, Mona guano third. In 1896 ground Florida phosphate was first and slag phosphate second in yield of beans. In 1897 the guano produced nearly twice as large a yield as any of the other plots, S.C.rock-phos.produced the second largest yield.

The experiment would have been much more valuable if there had been check plots with no phosphorous and also with no fertilizers of any sort.

In 1886 Walter Balentine started an experiment with phosphates at the Maine Station. The soil on which these experiments were conducted was a clay loam. Plots were 1 x 3 rods including one twentieth acre each. Dissolved bone black, raw bone, and S.C. rock phosphate were the three carriers of phosphorous that were compared.

On next page table shows amount and kind of fertilizers applied. Amount of phosphorous fertilizer applied, in each case furnished the same number of pounds of phosphorous per acre. Cost of S.C. rock phosphate was

about one third that of the other two forms.

Plots.	Fertilizers applied	Lbs. per A.
1, 7, 13	Received no fertilizer	
19, 25, 31	" " "	
	Dissolved bone black	400
2, 8, 14	Muriate of potash	100
	Sulphate of ammonia	200
	Raw bone meal	350
3, 9, 15	Muriate of potash	100
	Sulphate of ammonia	140
	Fine ground S.O. rock phosphate	300
4, 10, 16	Muriate of potash	100
	Sulphate of ammonia	200
	Muriate of potash	100
5, 11, 17	Sulphate of ammonia	200

This experiment was continued for nine years the last part being done under the direction of W.H. Jordan, and a history of the work is given by him in the annual report of the Maine State College for 1894.

Year	Crop	Treatment
1886	Oats	Fertilizer applied
1887	"	" "
1888	Hay	No fertilizers.
1889	Fallowed	Fertilizer applied
1890	Peas	No fertilizers
1891	Oats	" "
1892	Peas	" "
1893	Corn	Fertilizers applied
1894	"	" "

It is seen that during the nine years five applications of fertilizers have been made and eight crops produced.

On following page is given the summary of yields per acre for eight years.

Summary of yield per acre for eight years.

		No fertili- lizer plots 1,7,13	D.B.B. 2,8,14.	Ground Bone 3,9,15.	S.C. Rock. 10,16,4	N & K only 5,11,17
Oats crop	Grain(bu)	52.2	77.7	71.4	67.7	60.5
of 1886	Straw (lbs)	1994	3414	3134	2383	2564
Oats crop	Grain	25.0	36.3	29.9	33.1	31.0
of 1887	Straw	1200	2240	1610	2033	1643
Hay, 1888		2566	2434	2300	2566	2234
Peas	Grain	12.3	15.0	15.7	14.1	12.7
1890	Straw	664	943	976	914	660
Oats	Grain	36.4	42.1	43.0	36.3	40.5
1891	Straw	723	983	1090	776	704
Peas	Grain	7.8	6.1	6.3	5.1	7.3
1892	Straw	749	756	696	552	740
1893	Corn (air dry) lbs.	395	1415	1326	1076	905
1894	" " " "	749	2926	3033	2631	1379
Total Yield (3 crops) lbs.		13383	21381	20610	18933	13320
Total increase due to phos.			4531	3790	2163	
Annual	" " " "		570	474	270	

In this experiment we get results opposed to all the other experiments, which we have so far considered, in that the soluble form of phosphorus, dissolved bone black gave a larger increase than the insoluble forms, raw bone or S.C. rock phosphate. Three of the eight crops harvested were oats and this may in some measure account for the smaller increase due to raw

bone or S.C. rock phosphate. For it is noticeable from previous experiments that oats do not have the same power to utilize insoluble phosphates that corn^w wheat or hay do. In the hay crop of 1883 the insoluble raw bone meal and S.C. rock both gave larger yields than the dissolved bone black, and in the corn crop of 1894 raw bone meal produced the largest yield. Summing up the yields for the eight years in lbs. per acre we see that the dissolved bone black produced an average annual increase of 100 lbs. more per acre than the raw bone meal. However, the S.C. rock phosphate which produced the smallest average annual increase, made the gains at the smallest cost, for the dissolved bone black cost approximately three times as much as S.C. rock phosphate. So, even though the soluble form produced the largest yields we can not say that the soluble form is superior.

The Alabama, Delaware, Louisiana, New Hampshire and New Jersey stations have done some work with phosphates, but in most cases the experiments lasted but one or two years and the results are of no particular value in our case for it is a well known fact that for the first season the more extensive soluble phosphates give the largest yield.

WORK DONE IN ENGLAND

In the Journal of the Royal Agricultural Society of England there are records of work which was done with phosphorous fertilizers as early as 1843. However, many of these experiments are not of much value now for they used materials which are not in use at the present time.

In 1880 Dr. Augustus Voecker, Consulting Chemist to the Royal Agricultural Society, began a series of experiments on Warrens field, which

had been granted to the society by the Duke of Bedford. The field is a sandy clay soil. The phosphates compared were: finely ground corrolites, dissolved corrolites, finely ground Redonde phosphate, dissolved bone meal, precipitated phosphate, raw bone meal and Peruvian guano. The experiments were run in duplicate and were continued until 1886. The rotation used, was sweedes barley, clover and oats. The clover crop of 1882 was a failure. The fertilizers were applied as shown in the following table to the sweede crop of 1880, and were not again applied until 1884 when the second rotation was commenced. It was decided to divide each plot in half this year and apply the same fertilizer to the plots that was applied in 1880, but in different amounts. The clover crop of 1886 was so full of weeds that no record was made of its yield and the experiment was discontinued. The following tables give fertilizers applied and yields from 1880 - 1885 inclusive.

Yields 1930 and 1931 per acre.

Plot	Fertilizer app.in 1930	Amt.of Fertilizer applied,	Sweedes 1930		Barley 1931	
			Ave.of Increase 2-plots due to Fert'zr.		Ave.of Increase 2-plots due to Fertl'zr.	
1-A&B	Raw carpolites	650%	42254	7001	34.0	-9.5
2-A&B	Dissolved "	500	48575	13322	40.3	-3.3
3-A&B	Redonda phosphate	1000	46251	10995	40.0	-3.5
4-A&B	Dissolved bone meal	350	46539	11333	44.0	-0.5
5-A&B	Precipitated phosphate	450	45937	10681	42.3	-0.3
6-A&B	No fertilizer		35256		43.5	
7-A&B	Bone meal	300	38568	3312	39.3	-4.3
8-A&B	Dung	20T 10T	49354	14601	51.0	+7.5
9-A&B	Dung & dis. coohrotes	500%	48391	13435	41.3	-2.3
10-A&B	" " raw "	20T 650%	49916	14660	42.8	-0.8
11-A&B	Chalk	5T 300	40133	4877	42.3	-0.8
12-A&B	Dis. carpolites & Per. guano	250	50913	17662	42.5	-1.0

Yield of Oats per acre for the year 1883.

Plot	Fertilizer applied in 1880	Oats - 1883		
			Ave of 2-plots.	Increase
1-A&B	Raw corbolites	Clover crop for 1882 a failure	64.7	4.6
2-A&B	Dissolved "		72.4	12.3
3-A&B	Redonda phosphate		73.7	18.6
4-A&B	Dissolved bone meal		61.3	1.2
5-A&B	Precipitated phosphorus		61.1	6.0
6-A&B	No manure		60.1	
7-A&B	Bone meal		61.2	0.1
8-A&B	Guano		70.4	10.3
9-A&B	Guano & corbolites		63.8	6.7
10-A&B	" " raw corbolites		62.7	2.6
11-A&B	Chalk		71.9	11.8
12-A&B	Dissolved corbolites & guano		64.7	4.6

Yields per acre of Sweetdes for 1884 and Barley for 1885

First half of plots.

Plot	Fertilizer applied 1st half in 1884	lbs. per Acre	Sweetdes 1884		Barley 1885	
			Roots per A Yield	Increase	Yield	Increase
1-A&B	Ground corpolites	300	24450	10211	37.5	-10.0
2-A&B	Diss. "	300	23137	9043	47.8	0.3
3-A&B	Redonda phos.	300	23320	14531	45.4	- 2.1
4-A&B	Dissolved bones	300	27994	13655	47.5	
5-A&B	" corpolites	200	25230	10981	42.2	- 5.2
6-A&B	No manure		14073		47.5	
7-A&B	Bone meal	300	23349	9710	41.9	- 5.6
8-A&B	Dung	10T	29262	16423	50.1	2.6
9-A&B	Dung & dis. corpolites	10T	30416	16177	48.2	- 4.3
10-A&B	" " ground "	10T	30791	16552	46.7	- 0.8
11-A&B	Dissolved corpolites	200	22174	7935	46.8	- 0.7
12-A&B	Dis. corpolites & Nitrate of soda	200 100	18129	3830	41.3	- 5.7

Dr. Augustus Volecker also conducted another experiment on Lansone field very similar to the one on Warrens field. The soil contained but little lime and aluminum and a good deal of iron oxide. Each plot was one fourth acre in size, and was separated from the other plots by a path two and one half feet wide. Rotation followed was sweetdes in 1881, barley in 1882, peas in 1883 and wheat in 1884. The sweetdes were fed off on the land by sheep, with the addition of barley meal at the rate of 400 pounds per acre, and 200 pounds decoliticated cotton cake. Tables following give the kind and amount of fertilizer applied in 1881 and yield per acre for the four years.

Yield of Sweetdes 1881 and Barley 1882 per Acre.

Average of duplicate plots.

Plots	Fertilizer app. in 1881	lbs. per Acre	Sweetdes per A.	Increase due to Fert'liz.	Yield of barley	Increase due to Fert'liz.
1-A&B	No manure		39210		45.8	
2-A&B	Grd corpolites	500	51339	12429	59.3	13.5
3-A&B	Dis. "	500	54774	15564	51.2	5.4
4-A&B	Redonda phos.	500	53360	14150	51.7	5.9
5-A&B	Precipitated phos.	400	48713	4503	40.5	- 5.3
6-A&B	Bone meal	300	50212	11002	49.9	4.1
7-A&B	Dissolved bones	300	53431	14224	49.1	3.3
8-A&B	Acid bone and Per. guano	300 250	54070	14360	51.3	5.5

Yield of Peas per acre for 1883 and Wheat, 1884.

Average of duplicate Plots.

Plots	Fertilizer app. in 1881	Amt. per Acre	Yield of Peas bu.	Increase due to Fertl'zr	Yield of Wheat	Increase due to Fertl'zr
1-A&B	No manure		39.1		30.3	
2-A&B	Ground corrolites	500	41.8	127	32.3	2.0
3-A&B	Dissolved "	500	44.5	54	33.7	3.4
4-A&B	Redonda phos.	500	43.3	4.2	33.5	3.2
5-A&B	Precipitated phos.	400	40.5	14	31.7	1.4
6-A&B	Bone meal	300	43.6	45	31.7	1.4
7-A&B	Dissolved bones	300	42.7	33	31.6	1.3
8-A&B	Acid bone & Per. guano.	300 250	42.9	33	35.5	5.2

In this work done by Augustus Voelcker the results do not agree with the work done at the experiment stations in the United States. They are not exactly comparable with the experiment station work, for the fertilizers used by Voelcker were not complete fertilizers, and the yields were no doubt influenced by the lack of some other elements besides phosphorous. However, we get a comparison between acid bone and raw bone meal. In four crops raised out of five on Warrens field the soluble form was superior to the raw. In the case of the four crops grown on Lansons field the raw bone meal was slightly ahead in three cases. In comparing the raw and dissolved corrolites, the dissolved form was ahead in five cases at Warrens field, and it was in the lead in three out of four cases

at Dansont field. So we see that in almost all cases in the experiments on both fields the soluble form was the best. These soils had likely been under a system of exhaustive cropping for a long time and were probably deficient in humus which would account for the relative poor showing of the insoluble forms. Lack of humus is indicated by the large yields on all plots where dung was applied.

-- SUMMARY AND CONCLUSION --

In summing up the work which we have gone over, it seems that the work done at Ohio, Pennsylvania and Maryland is the most important. For in each case a definite rotation was followed, all the elements of plant growth were supplied, and the experiments were carried on for a sufficient length of time to give some valuable and reliable results. The work at Ohio and Maryland is still in progress. In order to make a comparison of these results, a summary of the yields for each experiment is given on the following pages.

Average yield of Wheat per Acre for three years at Pennsylvania.

Plot	Fertilizer applied every alternate year	lbs. of Fertilizer	Grain	Straw	Increase due to phos.
A&G	Dissolved bone black	200	2823	3014	-2.34
B&H	" " " (rev.)	200	2990	3208	-0.69
C&I	Raw bone meal	150	3153	3339	+1.01
D&J	S.C. rock phos.	150	3556	3333	+0.99
E&K	No phosphorous		3057	2793	
F&L	Nothing		2252	1933	

Average yield of Corn per Acre for three years at Pennsylvania.

Plot	Fertilizer applied every alternate year	lbs. of Fertilizer	Grain	Stover	Increase due to phos.
A&G	Dissolved bone black	200	4986	1942	3.13
B&H	" " " (rev)	200	4960	1927	3.92
C&I	Raw bone meal (ground bone)	150	5196	2072	11.29
D&J	S.C. rock phosphate	150	4734	1908	6.96
E&K	No phosphorous		4038	1667	
F&L	Nothing		3307	1027	

Average yield of Grass per Acre for three years at Pennsylvania

Plot	Fertilizer applied every alternate year	lbs. of Fertilizer	Hay - lbs.	Increase due to phos.
A&G	Dissolved bone black	200	3157	575
B&H	" " " (rev.)	200	3300	303
C&I	Raw bone meal (ground bone)	150	3365	373
D&J	S.O. rock phosphate	150	3133	341
E&K	No phosphorous		2492	
F&L	Nothing		2048	

Average yield of Oats per Acre for Three Years at Pennsylvania

Plot	Fertilizer applied every alternate year	lbs of Fertilizer	Grain bu.	Straw lbs.	Increase due to phos.
A&G	Dissolved bone black	200	43.75	1337	-1.79
B&H	" " " (rev)	200	47.10	1326	+1.56
C&I	Raw bone meal (ground bone)	150	49.32	1525	+3.85
D&J	S.O. rock phosphate	150	43.24	1557	+2.70
E&K	No phosphorous		45.54	1217	
F&L	Nothing		38.81	1095	

Table from "Ohio Farmer" giving results of all Experiments on phosphorous comparison up to the present time. Including 33 crops of wheat, 32 crops of hay and 18 of each corn and oats.

Average increase per acre.				
	Corn bu.	Oats bu.	Wheat bu.	Hay lbs.
Acid phosphate	12.17	16.00	11.35	312
Dissolved bone black	11.43	14.17	12.25	573
Raw bone meal	9.13	14.02	11.63	738
Slag phosphate	12.20	14.64	12.42	843

Table showing average yields per acre with different forms of phosphorous, and different kinds catch crops turned under at Maryland.

	Three crops Corn		Wheat - 1 yr.		Hay 1 yr
	Grain	Stover	Grain	Straw	
Ave of 4 nothing plots. (5,10,15,20)	43.3	2432	21.3	2601	3362
" " 3 soluble plots (1,2,3,4)	43.3	2434	33.7	3315	4350
" " 2 rev. plots (4,6)	45.7	2673	32.3	3360	4525
" " 5 insol. plots(7,8,9,11,12)					
Crimson clover turned under	43.0	2537	31.1	3337	4020
Ave of 4 insol.plots (3,9,11,12)					
Crimson clover turned under	49.0	2540	32.4	3342	4025
Ave. of 4 insol.plots(13,14,16,17)					
Nothing turned under	45.8	2673	33.7	3311	3338
Ave of 4 insol.plots(13,19,21,22)					
Rye turned under	42.1	2433	33.5	3511	3900
Ave of 12 insol.plots (3,9,11,12, 13,14,16,17,19,21,22)	45.5	2552	33.2	3638	3921

	Three crops Corn		Wheat - 1 yr.		Hay 1-yr.
	Grain	Stover	Grain	Stover	
Ave of three bone meal plots (8,13,18)	47.8	2636	35.3	3903	3867
" of 3 slag.phos. plots (9,14,19)	45.8	2549	36.0	4195	4217
" " " S.C. rock plots (11,16,21).	44.3	2531	31.5	3508	4217
" " " Florida soft phos. plots (12,17,22)	44.2	2492	30.0	3147	4050

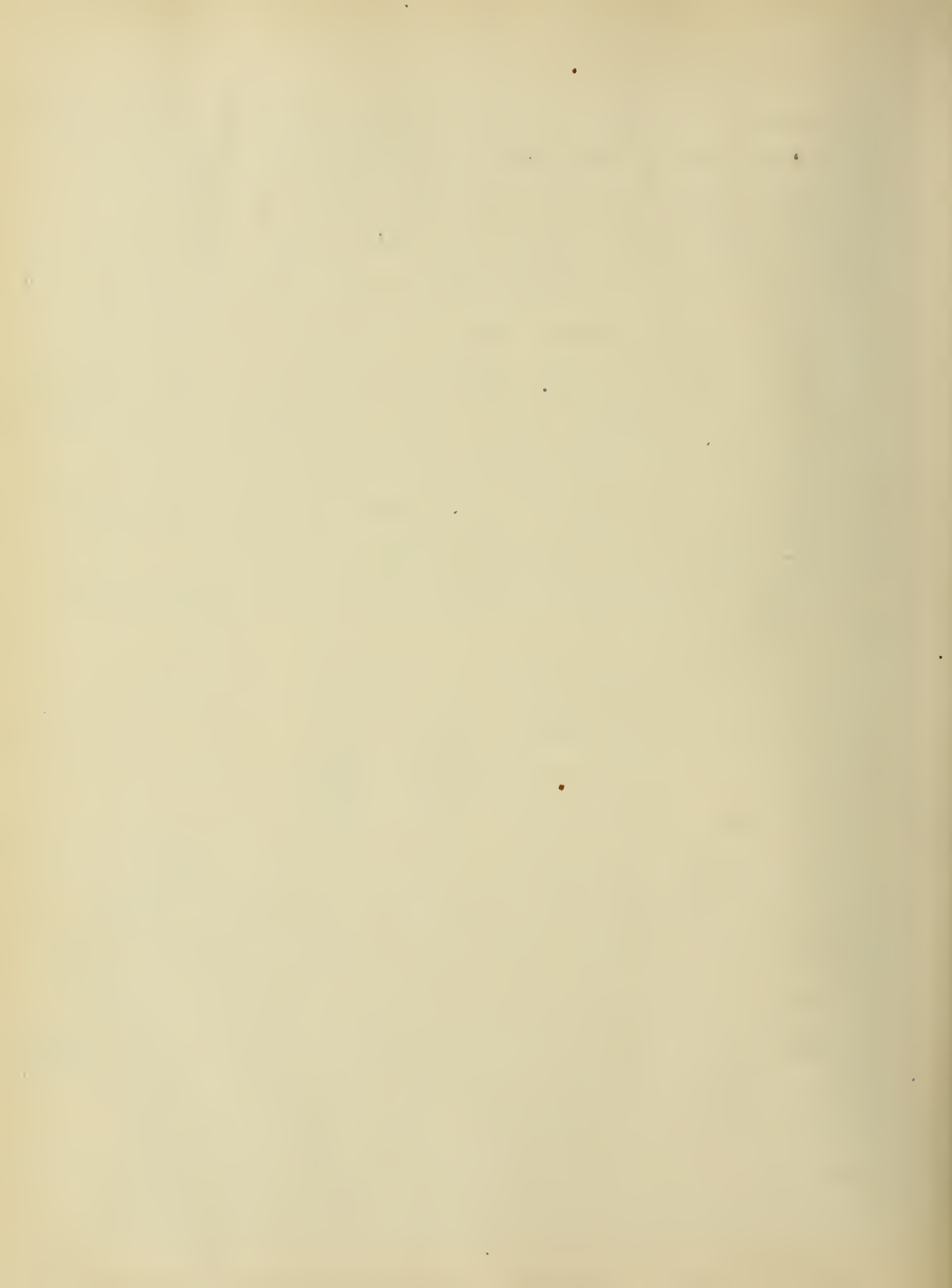
From these experiments perhaps the most noticeable thing is, that in all cases phosphorous in any form, nearly always produced a large increase, showing that the soils of these three states is very deficient in available phosphorous. In all these experiments the insoluble form of phosphorous is on the whole superior to the soluble form. At Pennsylvania we see that raw bone meal is unmistakeably the most profitable form of phosphorous for that soil. The S.C. rock phosphate gave nearly as good returns on the wheat and oat crops, and on the whole gave nearly as good financial results. The superiority of the raw bone meal is no doubt due largely to the fact that the soil contained a large excess of limestone which aided very much in the decomposition of the organic matter in the raw bone. Looking over the summary of the yield at Maryland we see that for the years that corn was grown the raw bone was ahead of the other forms of phosphorous, making an average yield for the three years, 47.8 bushels. Slag phosphate made the second highest yield, 45.8 bushels, while the three plots which received soluble phosphates made an average yield of only 43.8 bushels. With wheat, slag phos-

phate produced the largest yield, 36.0 bushels with raw bone meal a close second, 25.3 bushels. With the hay crop all the other insoluble forms rank slightly ahead of the raw bone, and the reverted and soluble phosphates were both superior to any of the insoluble forms. On the whole the insoluble forms were in the lead, and while in the case of the corn crop the raw bone meal and slag phosphate were in the lead, yet on the wheat and hay crops the mineral phosphates compare favorably with the more expensive raw bone and slag phosphate. This is worth noting when we consider that the natural phosphates cost only about one third as much as the raw bone. At Ohio we see that on the whole slag phosphate is in the lead making the largest gains in every case except that of oats.

The total value of these increases found by using prices given on page 25 are:

Slag phosphate - - - -	-\$13.75
Acid phosphate - - - -	17.70
Dis. bone black- - - -	16.81
Raw bone meal - - - -	15.71

If we introduce steamed bone meal into this series by means of comparison with raw bone meal, as obtained from an experiment at Strongsville, where raw and steamed bone meal were compared; we see that steamed bone meal is decidedly superior to any of the other phosphates, ranking as \$19.89, nearly \$1.00 above the slag phosphate. It would be very interesting if steamed bone meal had been used in some of the phosphorous experiments which we have considered. For from this it seems that steamed bone is much the best form in which to obtain phosphorous. Charles E. Thorne director of the Ohio station says: "At present, steamed bone



meal furnishes phosphorous in probably the cheapest and most effective form in which it can be bought", and "the use of acid phosphates has been abandoned at this station, except to continue experimental work."

From these experiments it seems that insoluble forms of phosphorous are much superior to the acid or soluble forms. At Ohio Steamed Bone Meal stands first with slag phosphate second. At Pennsylvania raw bone is first and S.C. rock second. At Maryland raw bone meal stands first with slag phosphate second. So no doubt the most profitable form of phosphorous is largely determined by the character of the soil. For raw bone does not decompose readily in an acid soil, and humus is essential for profitable returns from a mineral phosphate.

- APPENDIX -

References.

Alabama Experiment Station Bulletin (1889) No. 5, (New Series), pages, 3-13; 1890 No. 13 (New Series) page 26.

Report of the Connecticut Board of Agricultural and Experiment Station for 1888, pages 113-140 and 1899 pages 203 - 239.

Delaware Experiment Station Bulletin, (1899) No. 43, pages 19-29; Annual Report of the Delaware College Agricultural Experiment Station, 1893, pages 193 - 202.

Florida Agricultural Experiment Station Bulletin, (1891), No. 13, pages 12-13.

U.S. Department of Agriculture, Farmers Bulletin No. 56, page 12.

Georgia Experiment Station Bulletin, (1893), No. 2, pages 35 - 37.

Louisiana Experiment Station Bulletin, (1888) No. 8, pages 12 - 13

(1898) " 27, " 466

Report of the Maine Agricultural Experiment Station for:

1899 - pages 105 1895 - pages 10 - 18

1890 " 79 - 101 1897 " 20 - 25

1891 " 126 - 144 1893 " 64 - 74

1893 " 13 - 25

1894 " 16 - 28

Bulletin No. 34 pages 3 - 19

Maryland Experiment Station Bulletin; (1890) No. 10, pages 33 - 39.

(1900) " 38 " 1 - 29

Annual Report of the State Agricultural Experiment Station for:

1892 - pages 197 - 201

1893 " 221 - 225.

Annual Report of the Hatch Experiment Station of the Massachusetts Agricultural College for:

1896 - pages 190 - 194

1897 " 14 - 19

1898 " 127 - 134

New Hampshire Agricultural Experiment Station Bulletin, (1898), No. 59, pages 189 - 190.

State of New Jersey Annual Report of the State Board of Agriculture for:

1881 - pages 101 - 104

1889 " 147 - 151

1895 " 18 - 99

Ohio Experiment Station Bulletin.

1893 No. 53 pages 31 - 32

1896 " 30 " 143 - 175

1899 " 110 " 65 - 68

1901 " 124 " 103 - 119

1902 " 134 " 39 - 101

1903 " 141 " 77 - 73

Annual Report of the Rhode Island Agricultural Experiment Station for:

1894 - pages 122 - 128

1896 " 327 - 343

1897 " 394 - 403

U.S.. Department of Agriculture, Year Book for 1894 pages 177 - 192.

Journal of the Royal Agricultural Society of England for:

1844 - Volume 4 page 403.

1845 " 5 " 443 - 468 and 605.

1846 " 6 " 531

1847 " 7 " 273

1855 " 16 " 90

1858 " 19 " 153

1861 " 22 " 69

1863 " 24 " 37

Second Series

1868 - Volume 4 page 176

1880 " 16 " 152

1881 " 17 " 92 - 110 - 107.

1882 " 18 " 320, 328.

Third Series.

1896 - Volume 7, page 563.





UNIVERSITY OF ILLINOIS-URBANA



3 0112 086763031